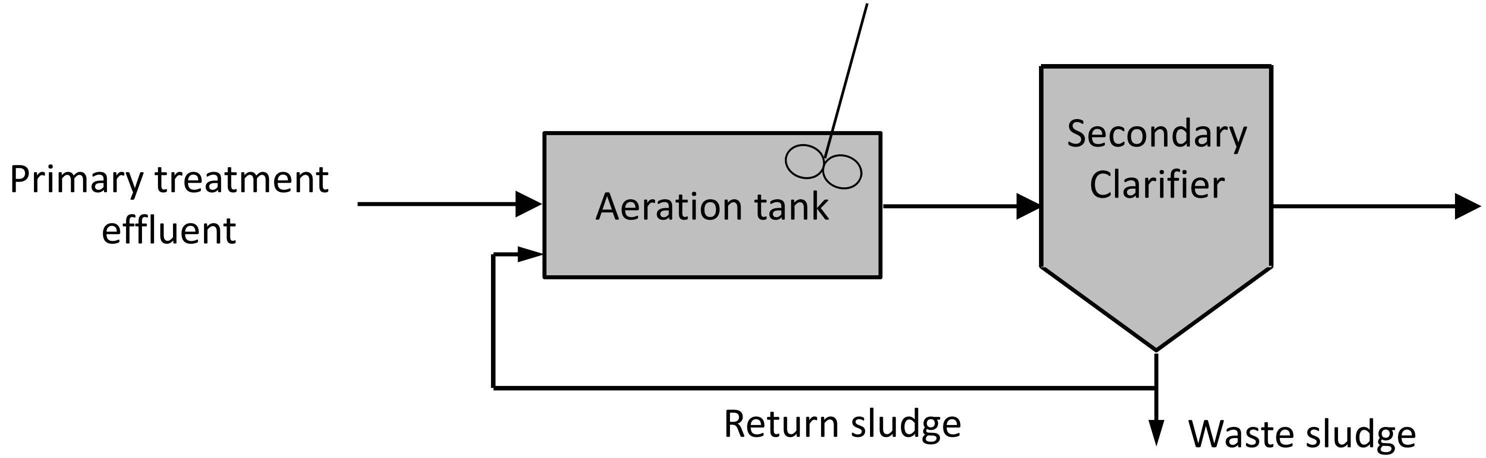
Wastewater treatment II

Wastewater treatment II

- Wastewater treatment processes
  - Secondary treatment – activated sludge; concept & analysis
  - Tertiary treatment
  - Sludge treatment and disposal

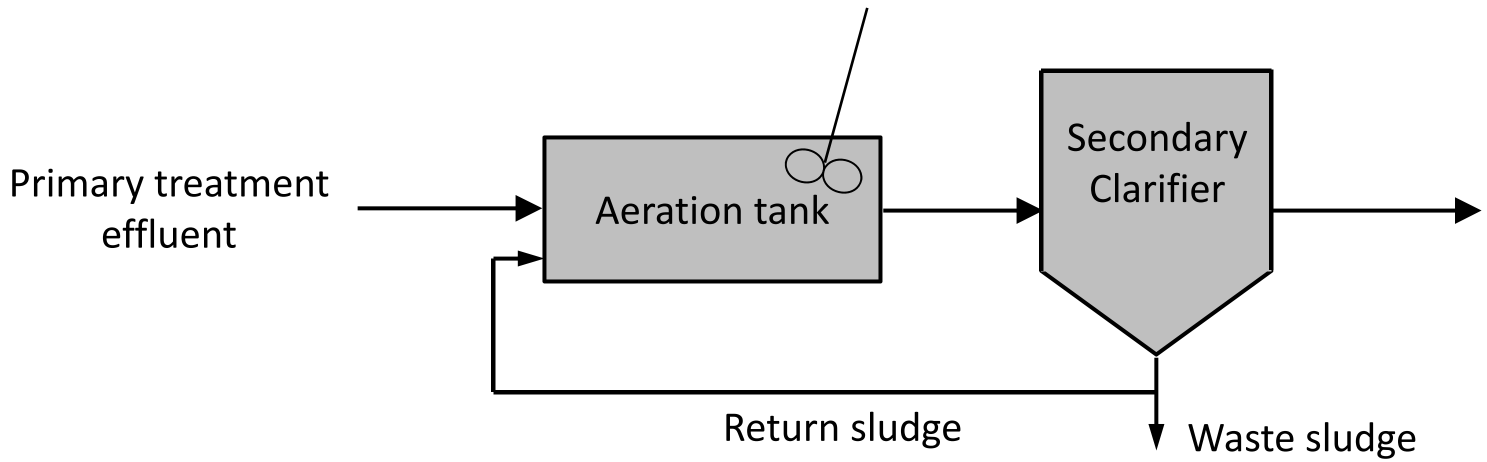
- Wastewater as a resource

Activated sludge process – concept



- A biological wastewater treatment technique using suspended microorganisms (dispersed growth)
- Aeration tank: a mixture of wastewater and microorganisms is agitated and aerated
- Wastewater BOD is removed by active microorganisms

Activated sludge process – concept



- Secondary clarifier: the microorganisms (also called biosolids or sludge) are separated from water by gravity
- Most of the settled sludge is returned to the aeration tank (Why? - We need a high population of microorganisms)
- A fraction of the settled sludge is wasted (Why? – microorganisms grow!)

Solids retention time (SRT)

- Recall hydraulic retention time

  t_0 = the time that fluid elements stay in the system

  $= V/Q$

- Solids retention time (or mean cell residence time)

  θ_c = the time that <u>microorganisms</u> stay in the system

- $t_0 \neq \theta_c$ if sludge is returned to the aeration tank (Why??)

Suspended solids in “mixed liquor”

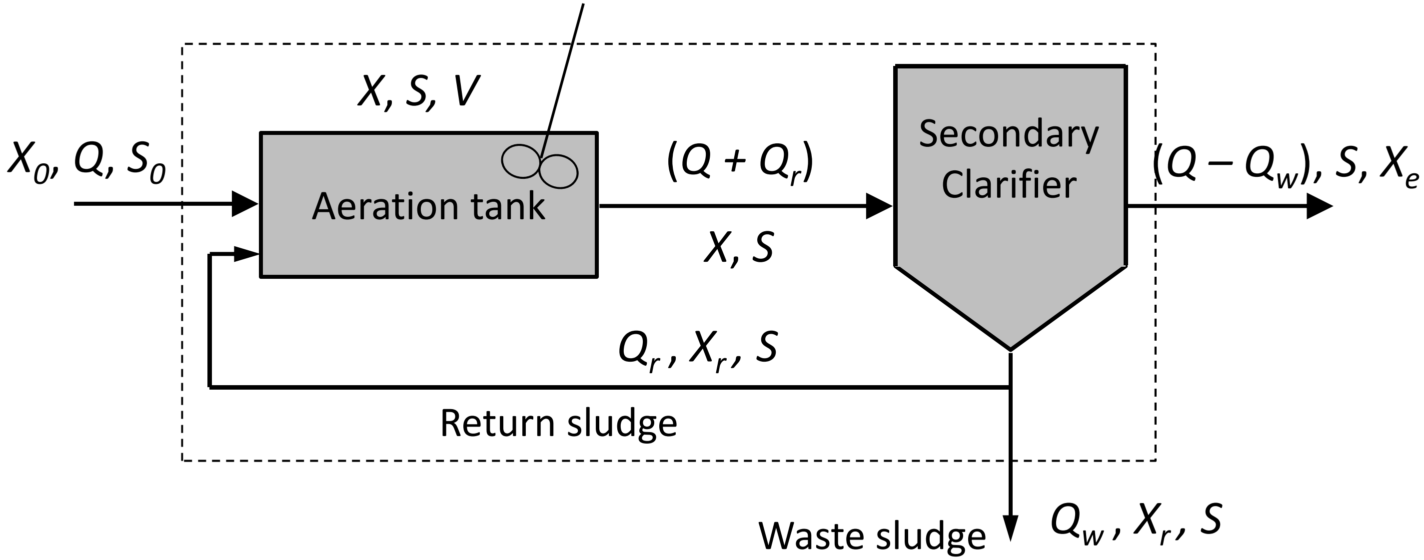
- The mixture of microorganisms and wastewater in
  ed “mixed liquor”
-
-

Analyzing activated sludge process

- Let's analyze the activated sludge process using two basic knowledge:
  - Monod kinetics (the reaction)
  - The system configuration (mass balance)

- We have two substances to analyze:
  - BOD (=substrate=food): the performance of the activated sludge process to treat wastewater
  - Microorganisms (=MLVSS): those that consume BOD; also related to sludge production

Control volume and assumptions



Assumptions:

X, X_e, X_r: MLVSS concentrations in aeration tank, effluent, and return sludge

i) Steady-state

ii) The aeration tank is a CMFR

iii) All reactions occur in the aeration tank

Mass balances

- Mass balance for substrate:

$$QS_0 - V\frac{\mu_m SX}{Y(K_s + S)} = (Q - Q_w)S + Q_w S \qquad \textbf{(A)}$$

- Mass balance for microorganisms:

$$QX_0 + V\left(\frac{\mu_m SX}{K_s + S} - k_d X\right) = (Q - Q_w)X_e + Q_w X_r$$

Solving the mass balance equations

<u>Additional assumption</u>: The influent and effluent MLVSS is negligible

- Mass balance for microorganisms

$$Q\cancel{X_0} + V\left(\frac{\mu_m S X}{K_s + S} - k_d X\right) = \cancel{(Q - Q_w)X_e} + Q_w X_r$$

$$\Rightarrow \quad \frac{\mu_m S}{K_s + S} = \frac{Q_w X_r}{VX} + k_d \qquad \textbf{(B)}$$

Representation of SRT

When the effluent MLVSS is negligible, we find:

$$\theta_c = \frac{MLVSS\ in\ the\ aeration\ tank}{MLVSS\ mass\ flow\ out\ of\ the\ system} = \frac{VX}{Q_w X_r}$$

(B): $$\frac{\mu_m S}{K_s + S} = \frac{1}{\theta_c} + k_d$$

(A): $$\frac{\mu_m S}{K_s + S} = \frac{QY}{VX}(S_0 - S)$$ ⇨ $$\frac{1}{\theta_c} + k_d = \frac{Y}{t_0 X}(S_0 - S)$$

Solutions

Effluent substrate concentration

$$S = \frac{K_s(1 + k_d\theta_c)}{\theta_c(\mu_m - k_d) - 1}$$

Aeration tank MLVSS concentration

$$X = \frac{\theta_c Y(S_0 - S)}{t_0(1 + k_d\theta_c)}$$

- SRT (θ_c) is a key design and operation parameter
- The effluent substrate concentration, *S*, is independent of the influent substrate concentration, S_0
- Higher S_0 → higher MLVSS in the aeration tank → more substrate biodegradation → same *S*

Analyzing activated sludge process

Q1: A completely mixed activated sludge process receives a primary effluent at a flowrate of 0.150 m^3/s with a BOD_5 of 84.0 mg/L. Calculate the solids retention time required to meet a secondary effluent standard of 10.0 mg/L BOD_5.

Following microbial growth parameters apply:

K_s = 100 mg/L BOD_5

μ_m = 2.5 day^{-1}

k_d = 0.050 day^{-1}

Y = 0.50 mg VSS/mg BOD_5

Analyzing activated sludge process

Q2: For the given activated sludge process, calculate the volume of the aeration tank to maintain MLVSS concentration of 2000 mg/L in the aeration tank.

Tertiary (advanced) treatment

- Goal: to improve the quality of the secondary treatment effluent
- Many of the Korean wastewater treatment plants now have advanced treatment process
- Further BOD and SS removal, nutrient removal, TDS removal, or the removal of refractory organic compounds
- Different processes can be used depending on the major target

Tertiary (advanced) treatment

- Available advanced treatment processes
  - **Granular filtration**
    - Additional removal of SS (including microorganisms)
    - Similar to water treatment
  - **Membrane filtration**
    - Additional removal of SS
    - Microfiltration is mostly commonly used for advanced treatment of wastewater
  - **Carbon adsorption**
    - Removal of non-biodegradable organic compounds (contributes to COD, but not to BOD)
    - Activated carbon is most commonly used as an adsorbent

Tertiary (advanced) treatment

- Available advanced treatment processes
  - **Chemical phosphorus removal**
    - Use chemical precipitants such as ferric chloride ($FeCl_3$), alum ($Al_2(SO_4)_3$), lime ($Ca(OH)_2$)
  - **Chlorine disinfection**
    - Removal of pathogens
    - Required process in the U.S. → considered as a conventional process, but often categorized as tertiary treatment

Sludge treatment

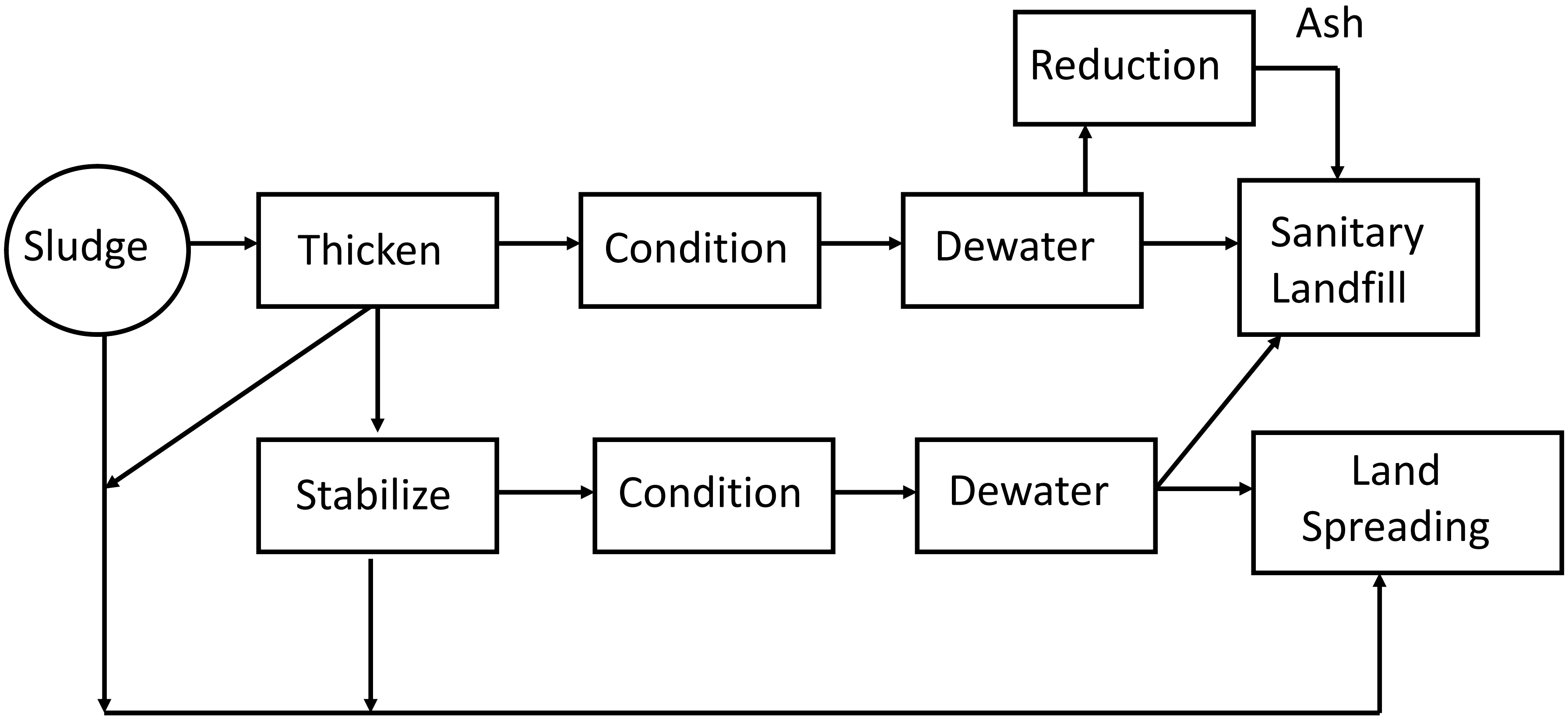
- Sources of solid waste from wastewater treatment
  - Bar racks & grit chamber
    - Inert, water can be easily removed
    - Generally not called as "sludge"
    - Truck directly to landfill after water removal
  - Primary and secondary treatment
    - Produces waste called "sludge"
    - High organic content → rapidly becomes anaerobic and putrefies
    - 3-8% solids for primary sludge & 0.5-2% solids for secondary sludge
  - Tertiary treatment: variable characteristics

Sludge treatment processes

- **Thickening**: separating as much as water possible from the raw sludge by gravity or flotation
- **Stabilization**: converting the organic solids to more inert forms
- **Conditioning**: treating the sludge with chemicals or heat so that the water can be readily separated
- **Dewatering**: separating water by vacuum, pressure, or drying
- **Reduction**: further reducing the solids and water when needed (ex: incineration)

Sludge treatment processes

- Organize the processes as needed



Sludge disposal

- **Land spreading:** can use nutrients and water in the sludge, but pathogen & heavy metal problem
- **Ocean disposal**: simple & easy, but not environmentally-friendly, now prohibited in Korea
- **Landfilling**: simple & easy, but takes a lot of landfill space
- **Composting**: use sludge as a valuable resource – but not well accepted by consumers

Wastewater as a resource

- A new paradigm: wastewater is not a WASTE, but a valuable RESOURCE
- Wastewater = water + nutrients + carbon (energy)
- Water reuse
  - Non-potable reuse: cooling water, irrigation, recreational use
  - Potable reuse: direct/indirect; can produce effluent with drinking water quality by reverse osmosis + UV disinfection
- Wastewater as a nutrient source
  - Irrigation of primary effluent
  - Use processed sludge as soil amendment
  - Precipitate nutrients to produce fertilizers

Wastewater as a resource

- Wastewater as an energy source
  - Wastewater treatment is a high energy process: accounts for 2-5% of the national energy consumption
  - Make the process "energy positive" → lots of energy savings!
  - Several ways to use energy in wastewater
    - CH_4 gas production from wastewater → heat / electricity generation
    - Electricity generation directly from wastewater (microbial fuel cells)
    - Using heat value of wastewater

Reading assignment

Textbook Ch 11 p. 538-571

Analyzing activated sludge process

Slide#13 solution)

$S = \frac{K_s(1+k_d\theta_c)}{\theta_c(\mu_m - k_d) - 1}$

$10.0\ mg/L = \frac{100\ mg/L \times \left(1+0.050\ day^{-1} \times \theta_c\right)}{\theta_c(2.5-0.050)\ day^{-1} - 1}$

$10.0\ mg/L \times 2.45\ day^{-1} \times \theta_c - 10\ mg/L = 100\ mg/L + 100\ mg/L \times 0.050\ day^{-1} \times \theta_c$

$19.5\ mg/L - day \times \theta_c = 110\ mg/L$

$\boldsymbol{\theta_c = 5.6\ days}$

Analyzing activated sludge process

Slide#14 solution)

$X = \frac{\theta_c Y(S_0 - S)}{t_0(1 + k_d \theta_c)}$

$t_0 = \frac{\theta_c Y(S_0 - S)}{X(1 + k_d \theta_c)} = \frac{5.6\ days \times 0.50 \times (84 - 10)\ mg/L}{2000\ mg/L \times (1 + 0.050\ day^{-1} \times 5.6\ days)} = 0.081\ day$

$t_0 = \frac{Q}{V},\ V = Qt_0 = 0.150\ m^3/s \times 86400\ s/day \times 0.081\ day = \mathbf{1050\ m^3}$